E82-10202
CR-168629

PROGRESS REPORT

MAGSAT FOR GEOMAGNETIC STUDIES OVER INDIAN REGION

Investigation Number M - 38

Author's name : Prof R G Rastogi

Organisation : Indian Institute of Geomagnetism
Colaba, Bombay 400 005, India

Type of Report : First Progress Report

Reporting Date : October 31, 1981

Investigation period : Jan 1, 1981 to Oct 31, 1981.

(E82-10202) MAGSAT FOR GEOMAGNETIC STUDIES OVER INDIAN REGION Progress Report, 1 Jan. - 31 Oct. 1981 (Indian Inst. of Geomagnetism, Bombay.) 42 p HC A03/MF A01 CSCL 08G G3/43

N82-23575

Unclas 00202

The investigation team consists of the following members:

R G Rastogi, B N Bhargava, B P Singh,
D R K Rao, G K Rangarajan, R Rajaram,
M Roy, B R Arora and A Seth.

The following collaborators participated in data analysis during this investigation period

N K Thakur and L Carlo

I. Summary

The major activities of the period were: (i) to prepare software for the reading of data tapes generated on IBM system on DEC-10 system accessible to this Institute; (ii) to create awareness of the utility of MAGSAT data amongst Universities, Research Laboratories and User Departments of Government of India; and (iii) to make operational the computer programs received from NASA on the DEC-10 computer system. The details of progress are enumerated below:

RECEIVED
DEC 1, 1981
SIS/902.6
M-038
TYPE II

II. Techniques

Since: (i) the MAGSAT data tapes were prepared on IBM system which has a 32 bit word size and the data are to be used on a DEC-10 system which has a 36 bit word size, and (ii) the data records were a mixture of integers and real numbers and each of the record has a different mixture; assembly language programs were developed for conversion of these tapes. The details are described on a publication : An Introduction to MAGSAT Data (by A Seth) prepared for circulation amongst the users of the data. This publication also includes brief details on : data organisation, parameters measured and parameters available on various tapes with their formats, methods for selecting relevant data with a few word on the exceptional quality of data available from MAGSAT mission.

The subroutines FIELDG sent by NASA was made operational and used with coefficients (g_m^n's and h_m^n's) supplied by GSFC to subtract main field part from CHRONFIN data to isolate components of crustal origin and of external current systems for studies related to these sources. One such study in progress attempts to look for evidence of equatorial electrojet currents using MAGSAT and ground measurements. Regional crustal anomalies were removed in this study by observing anomaly fields from quiet day morning

passes. For ring current contribution ground observations from the extensive network of Indian observatories were used.

For preparation of regional anomaly maps, a few passes were selected such that during the periods of satellite passage over Indian region, no magnetic disturbances were discernible from the chain of ground magnetic observatories in India. The core field using FIELDG and the external current component were removed with coefficients supplied by GSFC. The residuals have also been used with the subroutine UPCON supplied by NASA to test and run the program UPCON which will be needed to upward or downward continuation of anomalies.

III. Accomplishments

(1) CHRONINT, CHRONFIN and Investigator 'B' data tapes have been supplied to the Institute from MAGSAT mission. These data set provide for analysis a good vector measurements of earth's magnetic field over the Indian region which is known to have some complex sub-surface lineaments whose structures are yet to be completely understood. Anomalies in magnetic field from MAGSAT will provide useful information to study these lineaments. For study of external current system, it has provided with good ground network of magnetic observatories over

Indian region, measurements from both above and below the equatorial electrojet and low-latitude ionospheric current systems.

(2) The investigations are still in preliminary stage and thus the results have not been compared with those from other studies.

(3) Interesting areas identified for investigation with availability of MAGSAT data are sub-surface structure of Narmada Sone lineament and features of equatorial electrojet and counter-electrojet.

IV. Significant Results

(1) The organisations of two workshops by the Institute one on October 6 and 7, 1980 and the other on May 5 and 6, 1981 have created awareness on the ability of MAGSAT data. The first workshop was to introduce the richness of MAGSAT data to the Indian Geophysicists and Space physicists. As a follow-up of that Workshop a second one with title, "Space Borne Magnetic Data" was organised on May 5 and 6 jointly with Indian Space Research Organisation (ISRO) and Department of Science and Technology (DST) of Government of India. The workshop had a very good attendance. Presentations and discussions therein fully projected the utility of MAGSAT data in Geophysical studies.

(2) On reading and compatibility on DEC-10 system of the MAGSAT tapes (sent by NASA), a note has been prepared

by Dr Anil Seth (Ten copies of this publication are sent herewith). This note has greatly helped the MAGSAT data users in India.

(3) Some individual passes for such periods when ground magnetic observatories exhibited a quiet condition of magnetosphere were examined. From them core contribution and contribution from external currents were subtracted to isolate the components of crustal origin. In certain passes the vector anomalies are much more than the scalar anomaly. Whether this is an artifact of the method of reduction or is due to residual magnetisation is currently being investigated.

(4) The analysis of MAGSAT data in conjunction with ground observatory data for "evidence of equatorial electrojet currents in the ionosphere" has shown that a strong jet current flows below the satellite height in the ionosphere in the evening sector. For the morning sector the current is negligible. It is also noticed that the magnetic (N-S) variation$_H$ due to this current is less by a factor of two at the satellite height ($\sim$ 500 km) than that on the ground. There is also a strong indication that the east-west D variation at the satellite height is more than that at the ground level leading to a positive evidence on the existence of a vertical current in the ionosphere.

(5) The details of "MAGSAT studies over Indian Region" were presented by Prof B N Bhargava as an invited talk in the

Symposium on Interdisciplinary Approaches to Geomagnetism held in Bombay on May 18-20, 1981 (Ten copies of the presentation are enclosed).

(6) On invitation an article on "Mapping the Earth's Magnetic Field" was prepared for the most popular Science Monthly of India: Science Today. It appeared in their Sept 1981 issue. The article highlights the MAGSAT mission and its aims. It was authored by B P Singh (Ten copies of the same are enclosed).

V. Publications

(1) An Introduction to MAGSAT data by Anil Seth

(2) Results from MAGSAT Investigators at the Indian Institute of Geomagnetism by Anil Seth and B P Singh (Presented at IAGA Fourth Scientific Assembly at Edinburgh, Aug 1981).

(3) MAGSAT studies in the Indian Region : an invited talk given by B N Bhargava in the Symposium on Interdisciplinary Approaches to Geomagnetism, held at Bombay on May 1981.

(4) Mapping the Earth's magnetic field by B P Singh appeared in Science Today, Sept 1981, pp 39-42.

VI. Problems : Nothing significant

VII. Data Quality and Delivery : The quality of data supplied by MAGSAT mission is fabulous and the delivery is regular

VIII. Recommendations : Nothing for the present

IX. Conclusions

MAGSAT mission has provided a data of rare quality to the community of Geophysicists and Space physicists and it will open up many new frontiers in studies of solid earth physics and ionospheric-magnetospheric current systems. The Indian team is aiming to use this highly potential data to study sub-surface structure of Narmada Sone lineament and of the Himalayas. On the external current systems the good ground network of magnetic observatories vis-a-vis MAGSAT vector measurements have provided a rare opportunity to study many aspects of low latitude ionosphere.

AN INTRODUCTION TO THE MAGSAT DATA

ANIL SETH
Indian Institute of Geomagnetism

I. Introduction

The task before us is very much like searching for needles in a haystack. The 'needles' which may be discovered in the MAGSAT data are well-known to geophysicists and geologists and have been discussed by the other speakers at the Workshop. In this note, I shall confine myself to the description of the haystack and give an indication of our strategy of searching through it.

II. Data Variables

We are interested in the magnetic field as a function of position and time. But the satellite is not stationary. Therefore, the independent variable in our problem is the time and the other variables are given as a function of time. These are:

1. The position of the satellite, x,y,z.
2. The magnetic field: B_x, B_y, B_z.

An independent measurement of the scalar field is made using a Cesium Vapour magnetometer as a check on the vector field measurement

The position of the satellite is supplied at every 1 minute interval in Celestial and magnetic coordinates. The vector field is measured approximately 16 times a second, and scalar field 8 times a second.

As one day has 86400 seconds, simple arithmatic gives us:

1. the number of vector data points/day $3 \times 1.5 \times 10^6$
2. the number of scalar data points/day $.7 \times 10^6$
   that is, about 5 million values per day.

III. Chronicle Data Organisation on a Tape

Considerable thought and effort has to go into the format of the tapes which are supplied to the users. The data must be organised in a manner convenient for the Geophysicists. Yet, the sheer volume of data necessitates compromises. The data being supplied by NASA has the following format:

1. An orbit record containing position of the satellite for 128 minutes at every 1 minute interval (approx. 700 values in the record)

2. Scalar record containing the scalar field values for a 1 minute interval (approx. 500 values in the record)

3. a,b,c, Three vector records containing the B_x, B_y and B_z values respectively for a 1 minute interval (approx. 1000 values in each record).

The record types 2 and 3 are repeated for about the two hour period corresponding to the orbit record data.

The data is being supplied in IBM 360 binary representation. Each value equals 32 bits (i.e. binary digits), which is divided into 4 bytes of 8 bits each. (I shall return to the binary representation a little later).

Suppose instead NASA had supplied the data in a decimal code, e.g. a typical value may be ± 12345.6 i.e. 6 digits, the sign and the decimal point. Each character will be stored in a byte. Thus, the data in the decimal form will need 8 bytes, or twice as much magnetic tape as the binary form.

IV. A Magnetic Tape

The data supplied to us is on 9-track tapes with a recording density of 1600 bytes per inch.

One of the tracks is reserved for parity check on a tape and the remaining 8 are available for data (one 8 bit byte). With the above recording density, a 2400 ft. magnetic tape can store a maximum of 5×10^7 bytes. Actually the data on a tape will be blocked in records, which are separated by gaps of about half inch. Thus the tape can contain no more than about 4×10^7 bytes. This is 10 million values or about 2 days' data.

The satellite was in orbit for about seven months. The number of data tapes from NASA will, therefore, be in excess of a hundred.

Most of us feel at ease with card images, even when dealing with magnetic tapes. Let us compare the above tape format with a card image format:

1000 word record 2 1/2" data + 1/2" gap.
1 card (80 characters) 1/20" data + 1/2" gap!

V. The Orbits

The satellite orbits at an altitude between 300 to 500 km and has a period of about 90 minutes. Recall that vector data is taken every 1/16 sec. during which time interval the satellite will have moved by about half a kilometer.

Since the orbit of the satellite is polar, the data along a longitude will be about half a kilometer apart. On the other hand, in one day the number of passes over a latitude willbe twice the number of orbits i.e. 32. The average separation between these will be about 11°. During the lifetime of the satellite (about 7 months) the average separation along a latitude will be about 3'. This corresponds to a 6 km separation at the equator and 5 km separation at 30° latitude. However, not all days will be suitable for a particular problem under consideration. The expected separation of data along the latitudes will be larger, e.g. if there are 20 quiet days, then for field modelling the data along the equator will have an average separation of 60 km.

The anomaly resolution will, in addition be limited by:

1. the precision of the field measurements,
2. the accuracy of the knowledge of the satellite position and orientation, and
3. how well are the crustal anomalies resolved at the satellite height.

VI Comparison of IBM 360 and DEC 10

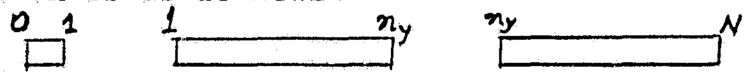
IBM word size is 32 bits; whereas that of DEC 10 is larger, 36 bits. An integer word of N bits is organized as follows:

1 bit for sign/N-1 bits for the magnitude.

Therefore, the magnitude of the largest integer in IBM is $2^{31}-1$ and that in DEC 10 is $2^{35}-1$. (on DEC 10 and IBM, a negative integer, X, is actually written as 2^N+X, i.e. $2^N-|x|$, so called 2's complement).

Real numbers are expressed as:

$+ X.b^Y$, where b is a constant and $1/b \leq x < 1$. The word organisation is as follows:



	Sign		Y		X
IBM:	1	+	7	+	24 with b = 16
DEC 10:	1	+	8	+	27 with b = 2

Therefore, the range of the reals on IBM is 16^{-64} to 16^{64} (10^{-76} to 10^{76}); while on DEC 10, it is 2^{-128} to 2^{128} (10^{-38} to 10^{38}).

Since the data records on the MAGSAT tapes were a mixture of integers and real numbers and each type of record had a different mixture, assembly language programs had to be developed for conversion of these tapes.

VII Outline of the Procedure for Selecting Relevant Data

1. a) Scan a tape for orbit records
   b) Select the records (according to Universal time) in which the satellite position was over the Indian subcontinent.
   c) Convert the satellite position from celestial coordinates to earth centred coordinates
   d) Mark the path over our region ($\sim$10 minutes).

2. a) Give the time interval when the satellite was over our region
   b) Select the scalar or vector data records for the given time periods
   c) Copy and save on disk (in DEC 10 binary form) for further analysis.

Generally, there are 2 passes at dawn and 2 at dusk between 60° and 100° east longitudes. Roughly about 1/2 hour's data each day willbe needed by us.

VIII A Few Words about Data:

A global spherical harmonic model for earth's field has been provided by NASA using 2 quiet days'data of the MAGSAT. Terms upto $n = 13$ have been included. This implies that the minimum separation between modes will be $\left(\frac{180}{13}\right) = 14°$ We would expect the global model to include regional anomaly features of about the above size. The differences between the total field and the model at satellite height are about 25 γ.

For example:

B_{scalar}	40214.5	40156.9	23929.8
B_{vector}	40214.7	40156.7	23928.5
B_{model}	40184.9	40137.3	23940.8

Comparing the total field from the scalar and the vector measurements, we have noticed that the differences are generally about 0.5γ or less and occasionally, up to about 1.3γ. The promised precision of the vector field was 3γ rms in each direction. It is as yet premature to comment on the actual reliability of data; however, the data appear to be of higher quality than was promised. It must be borne in mind that an error in the determination of the orientation of the satellite would give an erroneous vector field but a correct total field.

Anomalies at surface level will, however be larger, of the order of a few hundred gamma.

IX Acknowledgements

In addition to all my colleagues in the MAGSAT project, I would like to thank Mr. Sadanandan and Mr. Vijayaraman of NCSDCT (TIFR, Bombay) for helping me get started with the tape conversions.

ORIGINAL PAGE IS
OF POOR QUALITY

II.23

RESULTS FROM MAGSAT INVESTIGATIONS AT THE INDIAN INSTITUTE OF GEOMAGNETISM

ANIL SETH and B.P. SINGH
(Indian Institute of Geomagnetism, Colaba, Bombay 400 005, India)

Scalar and vector MAGSAT data were analysed to identify the anomalies in the ambient magnetic field over the Indian region. The data selected were for the quiet days of November and December 1979. In all passes over the Indian region the scalar data showed a consistent cyclic pattern in the anomalies. A low over the Indian ocean below Sri Lanka becoming zero near the tip of the peninsula, attaining a maximum over the peninsular region, becoming zero again near the Narmada-Sone lineament, going to a maximum (negative) value over the Himalays and then again becoming positive as one moves to the north. The vector data show a similar pattern, but the anomalies even in one component over certain regions are an order of magnitude greater than the anomalies in the total field. This is being associated to difference in direction of lithological magnetisation and the main field. The general pattern of the anomaly is in agreement with patterns seen in free air gravity anomalies prepared with terms of degree and order 13-22 based on GEM-10 model. A similar pattern is also noticed in subcrustal stresses exerted by mantle convention under Asia as computed by Liu (1978). Considering the above mentioned agreements and the fact that the free-air gravity anomalies with degree and order 0-12 terms show a different pattern, it can be concluded that over the Indian region magnetic anomalies have a significant contribution from lithological features.

MAGSAT STUDIES IN THE INDIAN REGION

by: B. N. BHARGAVA

It has been increasingly realised in recent decades that potential methods, gravitational and magnetic, assume great importance in the exploration for minerals and oil particularly because these provide coverage of vast areas at a relatively low cost. Magnetic exploration is based on the measurement of minute variations of the field caused by variations in the distribution of magnetized rocks, underlying the sedimentary rocks.

Measurements of the geomagnetic field in space began in 1958 with the Russian satellite KOSMOS-49 and have continued since then. The objectives of these experiments were to compute models of the main field originating in the core, to model secular variation and to investigate perturbations of the field of ionospheric and magnetospheric currents.

Table I shows the list of satellites which have measured the near-earth magnetic field, together with the inclination of their orbits, altitude range, life time, instruments and accuracy of field measurement. The shortcomings of most of these missions ranged from a lack of global coverage and highly elliptic orbit to limited accuracy in field measurement. Three satellites in the list, the Orbiting Geophysical Observatories 2, 4 and 6, however, made global measurements of the field between 1965 and 1971. The satellites, known as the Polar Orbiting Geophysical Observatories (POGO), measured the total field every half a second between altitudes ranging from 400 to 1500 km (Cain and Langel, 1971; Langel, 1974). With on-board tape recorders and near-polar

orbits, these satellites provided, for the first time, accurate measurements in space for field modelling, secular variation studies and researches in ionospheric and magnetospheric field perturbations.

In 1970, Zietz et al. considered the problem of detecting crustal magnetic anomalies at satellite altitudes (∼500 km) and by upward continuation of aeromagnetic maps and by comparison of satellite measurements with regional maps, they demonstrated that such anomalies should persist at satellite heights. The POGO satellites were not intended for solid earth studies. However, analysis by Regan et al.(1975) showed that low-altitude data acquired by POGO satellites contained measurable field originating in the earth's crust and that it could be separated from the field of currents external to the earth. Thus, the capability of space measurements in the detection and mapping of long-wavelength crustal anomalies was for the first time demonstrated by POGO data. A global anomaly map was prepared from these data by Regan et al.(1975) The reality of crustal origin of several anomalies in Regan's maps was confirmed by Langel et al.(1979) who showed a broad similarity of anomaly map of western Canada derived from upward continued aeromagnetic data with that computed from the POGO data.

Fig. 1 shows (in Polar equal area projection), upward-continued (to 500 km) aeromagnetic anomaly data to the left and scalar magnetic field anomalies derived by Langel et al. from POGO data to the right.

Fig. 2 shows an improved and refined global anomaly map with 2-gamma contours, prepared by Regan et al.(1975). Besides

other features, it shows the Bangui anomaly in west-central Africa, the high over Southern India and the low over the Himalayas.

With their high altitude range, resulting in most of the data having been acquired above 500 km and with the measurements limited to total field, the POGO satellites had serious limitations for application to solid earth studies. MAGSAT was designed to overcome these constraints. The two primary objectives of the MAGSAT mission were to provide global vector survey of the geo-potential field and a lower altitude scalar and vector measurement of crustal anomalies. The satellite, weighing 183 kg, was placed in a sun-synchronous twilight orbit on 30th October 1979. The initial orbital parameters were: perigee 352 km, apogee 561 km and inclination 96.76 degrees. The planned life-time of the spacecraft was 150 days but due to lower-than-anticipated solar activity, it lasted till June 11, 1980, providing data over about 220 days. The instrument module of the spacecraft had a three-axis fluxgate magnetometer of accuracy better than 3 nT for vector data, a dual-lamp cesium vapour magnetometer with an accuracy of 1 nT for scalar data and two star cameras for acquiring precision attitude data. Vector data from the satellite was intended to help resolve ambiguities in field direction, both, in field modelling and in anomaly mapping. Increased resolution and higher signal level from crustal sources are expected to result in considerable improvement over the POGO data. With perigee and apogee of 350 and 560 km respectively, it should be possible to compute anomalies longer than a few hundred kilometers.

Investigator tapes, being received in this Institute from World Data Centre A for Rockets and Satellites, are in Fortran

readable 360/91 Binary, 9-track and contain satellite position versus time to an accuracy of 300 m horizontally and 60 m vertically in addition to scalar and vector magnetometer data in Topocentric (NEV) coordinates with intermediate attitude (20 arc-min) and fine attitude (20 arc-sec) determination.

Out of about 55 proposals on a variety of investigations with MAGSAT data, received by NASA in response to their Announcement of Opportunity issued in September 1978, 34 investigations were selected by them after evaluation. Of these, 19 were from within USA. Of the foreign proposals selected, two were from India, one by the Indian Institute of Geomagnetism and the other by the Survey of India. Other foreign investigations were from Australia, Brazil, Canada, France, Italy, Japan and the U.K. The investigations are in general categories of geophysics, geology, magnetic field modelling, marine studies, magnetosphere and ionosphere and core/mant studies. The I.I.G. investigation is in two parts. Part I consists of five studies.

1. Regional magnetic anomaly and reference field maps,
2. Studies related to secondary effects in Sq field,
3. Studies related to induced currents associated with equatorial electrojet,
4. Studies of transient variations, and,
5. Low-latitude Bay structure.

Part II of the proposal from this Institute was sent to NASA in response to an earlier announcement and has been accepted by them as part of the first proposal. This part of the proposal is:

"Application of ground and satellite magnetometer data in the preparation of magnetic anomaly and magnetic reference field maps over India for purposes of delineating tectonic structure and understanding of the dynamics of the earth's crust and upper mantle".

The proposal from Survey of India is entitled "Analysis of MAGSAT and surface data of the Indian region" and envisages two investigations.

(i) Studies related to geomagnetic field modelling and description of the secular change,

(ii) Studies related to joint analysis of anomaly data in relation with data from other sources.

An agreement entitled "Provisions for participation" has been entered into by Indian Space Research Organisation and IIG with NASA. Under the agreement MAGSAT data and other material will be supplied, free of cost, to IIG. IIG shall provide to NASA the following reports.

(i) Progress reports at the end of each 4-month period up to and including 20 months after the date of first receipt of data,

(ii) A draft final report due 27 months after first receipt of data, and,

(iii) A final report, 2 months after NASA has returned the draft final report.

For conducting the investigations, IIG has constituted several internal investigating teams.

The time-invariant crustal field decays exponentially from the source at a rate approximately equal to the inverse of the distance cubed and its strength at MAGSAT altitude is small, between zero and 50 nT. The field of the ionospheric currents, however, decreases at a much slower rate with height. For the retrieval of the crustal signal, therefore, it is of vital importance to model the external field through detailed theoretical and empirical approach. For field modelling also it is necessary to compute and eliminate the temporally and spatially varying external fields. This assumes a greater importance as MAGSAT has operated in a period of high solar activity. Loomer et al.(1979) have studied the modelling of external disturbance fields using ground-base data of Canadian Observatories. In lower latitudes, however, the external fields, both of ionospheric and magnetospheric origin, are of wavelengths longer than the anomalies being mapped and can be eliminated without much difficulty. The external currents of importance in these latitudes are:

i) The Sq current system and the equatorial electrojet,

ii) Symmetric and asymmetric ring current,

iii) Neutral sheet current and magnetopause current, and,

iv) Induced currents.

IONOSPHERIC CURRENTS

Although the field of the ionospheric currents has been minimized by virtue of the twilight orbit of MAGSAT, this field can still have magnitudes comparable to the crustal signal at satellite altitude. Sugiura and Hagen (1979) have computed Sq field at satellite heights for epochs of both low and high solar activities.

Figure 3 shows the field of the Sq currents at 1700 hrs UT on December 27, 1964 at an altitude of 400 km in the latitude range of -60° to 60° suggesting an appreciable magnitude even during the solar minimum.

Figure 4 shows the scalar field of the Sq currents on May 24, 1958 during a period of high solar activity. The field at satellite heights is considerably higher; in fact the vertical force variation at the satellite altitudes is of a magnitude comparable to the variation at ground level.

Several techniques are possible for modelling and computing the field of the ionospheric currents. The field of the long-wavelength ionospheric sources can be modelled to first order by low-order terms in a spherical harmonic expansion (Langel and Sweeny, 1971; Cain and Davis, 1973). Computer programmes exist for providing correction for the ionospheric currents. Another modelling technique for computing the magnetic field due to complex 3-dimensional current systems, consisting of ionospheric currents and coupling currents to the outer magnetosphere (field-aligned currents) is the "Grid Cell" model (Kisabeth, 1979a, 1979b). The Sq current system and the equatorial electrojet can both be

modelled using the "Grid Cell" model. A grid with cells distributed from, for example, 60° N to 60° S can be used with appropriate Sq current vectors in each cell. Assuming that the current is confined to the ionosphere, the current system associated with each cell will be a simple ionospheric current sheet confined to the boundaries of the cell. Since the satellite has been orbiting near the edge of the Sq current system, the infinite horizontal sheet current approximation will not be valid, whereas the "Grid Cell" model should produce reasonably accurate model of the magnetic field at MAGSAT altitude.

Another technique which can be used for computing the ionospheric current densities from ground observations, together with a realistic model, is an inversion scheme like the one based on Backus-Gilbert method, developed by Oldenburg (1976). A method for eliminating temporal variations from aeromagnetic data has been proposed by Yarger et al. (1978). Assuming that the variations can be represented by a low order polynomial in time, the method removes these by minimizing the observed differences at flight-line/tie-line intersections using the least squares method.

MODELLING FIELDS OF DISTANT CURRENTS

The satellite measurements having been made during peak activity of the present solar cycle, a precise determination and elimination of the field of distant currents assumes importance in our investigation plan. Major sources of these fields are the ring current, neutral sheet currents and magnetopause currents.

An adequate and straight-forward procedure is the one based solely on the hourly D_{st} index, which, with the first harmonic

(diurnal) component of the DS field, should eliminate the field of the neutral sheet and magnetopause currents in addition to those of the symmetric and asymmetric ring currents. This index has been derived by Sugiura since IGY, 1957-58, and is currently published on a monthly basis providing provisional values which are finalised every year. While computing D_{st}, the first harmonic (m=1) of the disturbance field DS is also computed in addition to the longitude-independent component (m=0). With a view to improve the quality of the index, Sugiura has included Alibag as the fourth station in low latitudes for computing D_{st} and DS for the use of MAGSAT investigators. The index has been used for correction of POGO data by Cain and Davis (1973).

CORE FIELD AND REGIONAL FIELD MODEL

Removal of the core field is accomplished by the use of a geomagnetic field model to represent the core field. In recent years, several field models have been computed and these, with earlier models, have been reviewed by Barraclough (1978). In recent months and weeks, new spherical harmonic and polynomial models of the global field have become available at the National Centre for Geomagnetic Data (NGSDC), Boulder, Colorado. These are USD 80, a polynomial model based only on surface data, WC 80, a spherical harmonic model based on ground and aeromagnetic data, UO 61380, a spherical harmonic model based on satellite (including MAGSAT), airborne and surface data, MGST (3/80) and MGST (6/80), 13th degree and order spherical harmonic field models derived from two quiet days' (November 5 and 6, 1979) data from MAGSAT. Incidentally comparison of this model with earlier models shows that

between 1965 and 1980 the earth's dipole moment continues to decrease at the rate of 26 nT/year and, at this rate, the earth's field would reverse in about 1200 years. MGST (3/80) and MGST (6/80) are available at this Institute. In the coming weeks and months, updated models using MAGSAT data are likely to be computed culminating in a final model for use of MAGSAT investigators. At this Institute, therefore, we do not propose to compute a global model; our intention is to compute a regional model using surface and MAGSAT data. A spherical harmonic expansion to degree and order 13, which adequately represents the core field, is proposed to be attempted. In computing such a model, a spherical harmonic series of four variables (Latitude, Longitude, geocentric distance and time) will be fitted to the data set, free from fields of currents external to the earth, using least squares technique. Such a model is an essential requirement for the preparation of regional charts of geomagnetic components and to compute the anomaly field.

In magnetic exploration, the more important field components are the total intensity and the inclination; the former provides the background field and the latter gives the direction of the field and of the magnetization of rocks. Spherical harmonics show in detail the complex pattern of the field. An analysis by Alldredge et al. (1963) shows strong components with wavelengths less than about 300 km and even stronger ones of wavelength about 3000 km. Those of intermediate wavelengths are weak. The long wavelength components represent sources in the liquid core of the earth and the shorter wave-lengths are of origin in the permanent magnetization in the upper crust. Weak intermediate wavelength components show the non-magnetic character of the crust below the Curie point.

PROCESSING OF DATA FOR INTERPRETATION

Anomaly maps, basic tools for the study of the earth's crust, are proposed to be used in constructing geologic/geophysical models for resource assessment. Techniques are known for producing from scalar data, contour map of the measured average anomaly field at the average altitude of the data. Langel and Berbert (1979) suggest that these techniques should be applicable to vector data also at low latitudes; at high latitudes, field-aligned currents may cause difficulty in identifying the anomaly field in the vector data. A comprehensive review on reduction and analysis of satellite magnetometer data has recently been prepared by Regan (1979). The anomaly data is distributed over a range in elevation and has to be reduced to an arbitrary common altitude and inclination. A technique for the reduction of potential field data at different altitudes to a common plane has been outlined by Henderson and Cordel (1971) and has been used by Regan and Davis (1975) in the reduction of satellite magnetometer data. For reduction to common altitude, anomaly field can also be modelled by an equivalent source procedure. Mayhew (1979) has outlined one such procedure and has provided the mathematics involved. He has used the method for the reduction of POGO anomaly data ranging in elevation from 400 to 500 km to a constant elevation of 400 km.

Following the reduction to a constant elevation, a model of equivalent magnetization, that would cause the measured anomaly, is to be prepared, assuming a uniform crust of constant thickness. For this, the anomaly maps have to be inverted. Mayhew (1979) and Mayhew et al. (1980) have applied equivalent source method for

the case of a spherical earth with changing field inclination, assuming a constant 40 km thickness for the magnetized crust to derive magnetization in such a crust which would cause the anomalies seen by the satellite. The procedure is the same as used for reduction of anomaly data to constant elevation but with sources as 2° blocks of 40 km thickness, rather than dipoles. An approximate source function, developed for the anomaly due to such spherical prisms, has been provided by Mayhew in his paper. Such inversions are, however, not unique and their interpretation will require other data sources.

In a recent review, Hinze (1979) has summarised the technique of processing of magnetic anomaly data. With the availability of vector data from MAGSAT, he has suggested multi-parameter analysis techniques to reduce interpretation ambiguity. Comprehensive listing of the literature on mapping of magnetic anomalies and their geological interpretation has been provided by Hinze in the review.

In gravity and magnetics, techniques of computation of second derivatives and upward continuation as filters to remove anomalies from shallow sources have been used to extract longer wavelength anomaly field. The techniques can be applied in frequency domain. Downward continuation has been used in air-borne magnetics for anomaly separation. In a review of the derivative and upward and downward continuation Henderson (1960) presented a set of coefficients, which, when applied to gridded data, provide continued field at higher or lower levels. Use of small operators to two-dimensional field input values has been given by Mufti (1972). Upwar continuation approach has also been presented recently by Coles

and Haines (1979). Bhattacharyya (1979) proposed a method of efficient reduction of satellite data to a common altitude and inclination, adopting a procedure by Bhattacharyya and Chan (1977) for the reduction of aeromagnetic data over rugged terrain. The field at constant elevation can also be downward continued and components calculated for geologic interpretation. The procedure for upward continuation of potential field data has recently been reviewed by Bowman et al.(1979).

GEOLOGIC INTERPRETATION

Analysis and interpretation of satellite anomaly maps have received considerable attention in recent years in view of increased interest in long-wavelength anomalies. Langel and Herbert (1979) indicate that, in recent years, there has been a significant change in exploration philosophy. Regional broad-scale surveys are now more common to provide a geological environment suitable for economic deposits rather than the individual deposits. Air-borne and satellite surveys are rather complementary; air-borne data provides both, shorter and longer wavelength features, over limited areas and satellite data provides coverage over extended areas with more reliable information on longer wavelengths.

The state of art in processing, analysis and interpretation of long-wavelength magnetic anomalies has been reviewed in a special session of the 1976 Fall Annual Meeting of the American Geophysical Union. In recent years it has been established that crustal anomalies of longer wavelengths ($>$ 50 km) are indicative of geologic and tectonic features of the deep crust. With the advent of the

theory of plate tectonics, considerable interest has been created in the broad regional geological features which cannot be probed by aeromagnetic studies. A primary objective of the MAGSAT mission was to interpret the anomalies for geologic structure, composition, temperature of rock formation and remanent magnetism. NASA have also emphasized construction of a model of regional susceptibility contrast with vector data from MAGSAT with a view to improve the accuracy. Th is for acquiring information on shallow crustal features which are important for resource assessment and deep features related to faulting and earthquake mechanism. A study of the correspondence of gravity and magnetic anomalies should be particularly useful. Computation of cross-spectra and coherence should bring out wavelengths which are highly correlated.

The block diagram (Fig. 5) shows the sequence of operations for the satellite data processing, preparation of magnetic maps and analysis and interpretation of the crustal anomaly maps.

In the coming weeks and months an accelerated pace of analysis of the data is expected with the inflow of massive data from the satellite. When the multi-parameter study and interpretation of the anomaly maps is taken up, we can look forward to a period of exciting results.

REFERENCES

Alldredge, L.R., G.D. Vanvoorhis and T.M. Davis, A magnetic profile around the world, J. Geophys. Res., **68**, 3679, 1963.

Barraclough, D.R., Spherical harmonic models of the geomagnetic field, Geomagnetic Bulletin 8, Institute of Geological Sciences, 1978.

Bhattacharyya, B.K., Reduction and treatment of magnetic anomalies of crustal origin in satellite data, J. Geophys. Res., **82**, 3379, 1979.

Bhattacharyya, B.K., and K.C. Chan, Computation of gravity and magnetic anomalies due to magnetization and density in a localised region, Geophysics, **42**, 602, 1977.

Bowman, P.L., L.W. Bralle, Val W. Chandler,W.J. Hinze, A.J. Luca and Ralph R.B. Vontrese, Magnetic and gravity anomaly correlation and its application to satellite data, NASA Technical Memorandum 79702, 1979.

Cain J.C. and R.A. Langel, Geomagnetic survey by the polar orbiting geophysical observatories, in World Magnetic Survey 1957-1969, Ed. by A.J. Zmuda et al., IAGA Bulletin 28, 1971.

Cain,J.C. and W.M. Davis, Low latitude variations of the magnetic field, Symp. on low latitude satellite surveys, IAGA, Kyoto, 1973.

Coles, R.L. and G.V. Haines, Long wavelength magnetic anomalies over Canada using polynomial and upward continuation techniques, J. Geomag. Geoelectr., **31**, 545, 1979.

Henderson, R.G., A comprehensive system of automatic computation in magnetic and gravity interpretation, Geophysics, **25**, 569, 1960.

Henderson, R.G. and L. Cordell, Reduction of unevenly spaced potential field data to a horizontal plane by means of finite harmonic series, Geophysics, **36**, 856, 1971.

Hinze, W.J., Continental magnetic anomalies, Rev. Geophys. and Space Phys., 17, 257, 1979.

Kisabeth, J.L., On calculating magnetic and vector potential fields due to large scale magnetospheric current systems and induced currents in an infinitely conducting earth, in quantitative modell of the magnetospheric processes, Geophys. Managr. Ser., 21, Ed. by W.P. Olson, AGU, Washington D.C. 1979a.

Kisabeth, J.L., A new method of calculating magnetic fields due to large scale magnetospheric current systems using Z-transforms, submitted

Langel, R.A., Near-earth magnetic disturbance in total field at high latitudes, 1. Summary of data from OGO 2, 4 and 6, J. Geophys. Res., 79, 2363, 1974.

Langel, R.A. and J.H. Berbert, MAGSAT data Management Plan, GSFC, July 1979.

Langel, R.A., R. Coles and M.A. Mayhew, Comparison of Magnetic Anomali of Lithospheric origin measured by satellite and airborne magnetometer over Western Canada, NASA T.M. 80568, 1979.

Langel, R.A. and R.E. Sweeny, Asymmetric ring current at twilight local time, J. Geophys. Res., 74, 44, 1971.

Loomer, E.I., J.C. Gupta, J.K. Walker and H.L. Lam, Magnetic activity in the Canadian sector, Sept. 19-23, 1977, UAG Report, 1979.

Mayhew, M.A., Inversion of satellite anomaly data, J. Geophys., 45, 119, 1979.

Mayhew, M.A., B.D. Johnson and R.A. Langel, Magnetic anomalies at satellite elevation of Australia, Earth and Planetary Science Letters, 51, 189, 1980.

Mufti, I.R., Design of small operators for the continuation of potential field data, Geophysics, 37, 488, 1972.

Oldenburg, D.W., Ionospheric current structure as derived from ground-based magnetometer data, Geophys. J.R. astr. Soc., 46, 41, 1976.

Regan, R.D., The reduction and analysis of satellite magnetometer data, The Phoenix Corporation, 1979.

Regan, R.D., J.C. Cain and W.M. Davis, A Global Magnetic Anomaly Map, J. Geophys. Res., 80, 794, 1975.

Regan, R.D. and W.M. Davis, Reduction of satellite magnetometer data for geological studies, abst: EOS 56, 356, 1975.

Sugiura, M. and M.P. Hagen, Geomagnetic Sq variation at satellite altitudes: Is Sq correction important in MAGSAT data analysis? Geophys. Res. Lett., 6, 397, 1979.

Yarger, H.L., R.R. Robertson and R.L. Wentlend, Diurnal drift removal from aeromagnetic data using least squares, Geophysics, 43, 1148, 1978.

Zietz, Isidore, Andreason, G.E. and Cain, J.C., Magnetic Anomalies from satellite magnetometer, J. Geophys. Res., 75, 4007, 1970.

Legends to Diagrams

Fig. 1 Upward continued (to 500 km) aeromagnetic anomaly data (left) and scalar magnetic field anomalies derived by Langel et al. from POGO data (right) in polar equal area projection.

(after Langel et al., 1979)

Fig. 2 An improved and refined version of global anomaly map by Regan et al.(1975) with 2-gamma contours. Van der Grinten projection.

(after Langel, EOS, 60, 667, 1979)

Fig. 3 The field of the Sq currents at 1700 hrs UT on December 27, 1964 (solar minimum) at an altitude of 400 km in the latitude range of -60° to 60°

(after Sugiura and Hagan, 1979)

Fig. 4 The scalar field of the Sq currents on May 24, 1958 at an altitude of 400 km in the latitude range of -60° to 60° during a period of high solar activity.

(after Sugiura and Hagan, 1979)

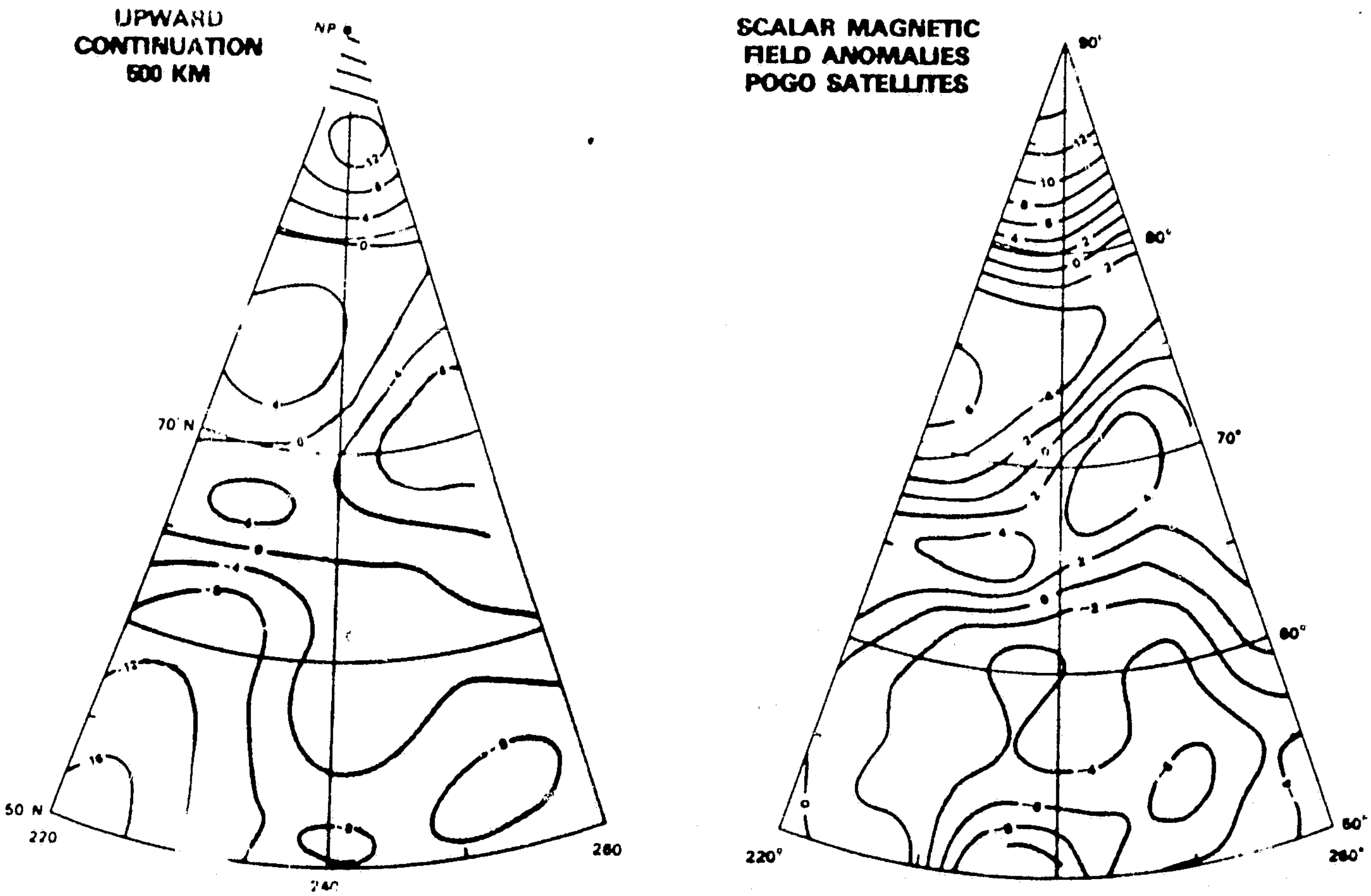
Fig. 5 Block diagram showing the sequence of operations for the satellite data processing, preparation of magnetic maps and analysis and interpretation of the crustal anomaly maps.

ORIGINAL PAGE IS
OF POOR QUALITY

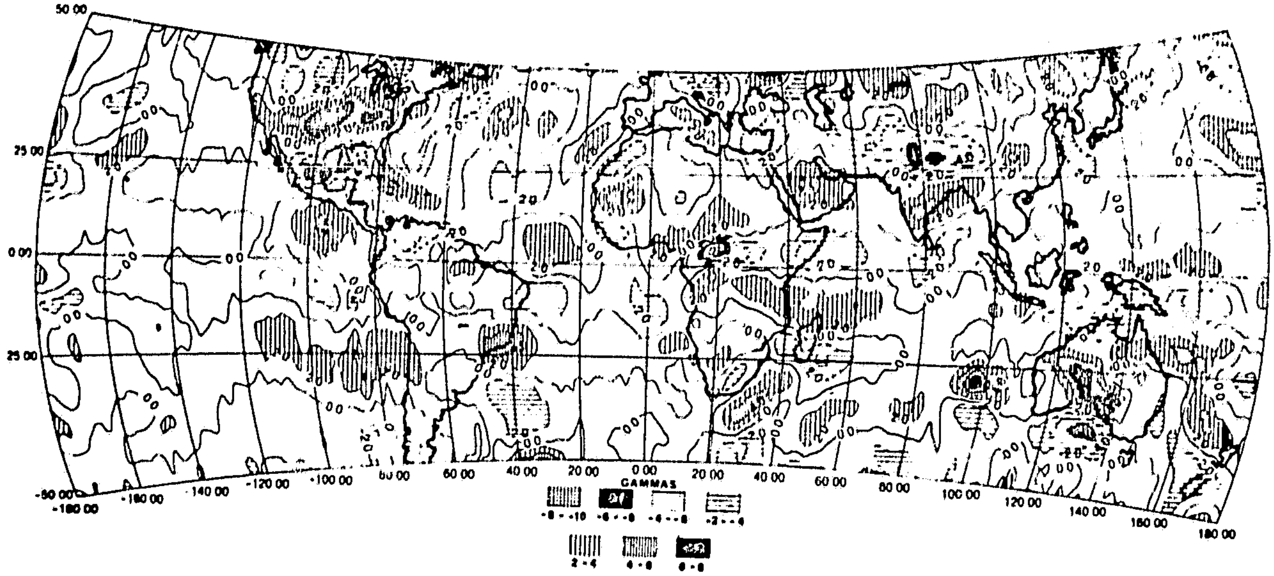
TABLE 1: Satellites Which Have Measured the Near-Earth Geomagnetic Field

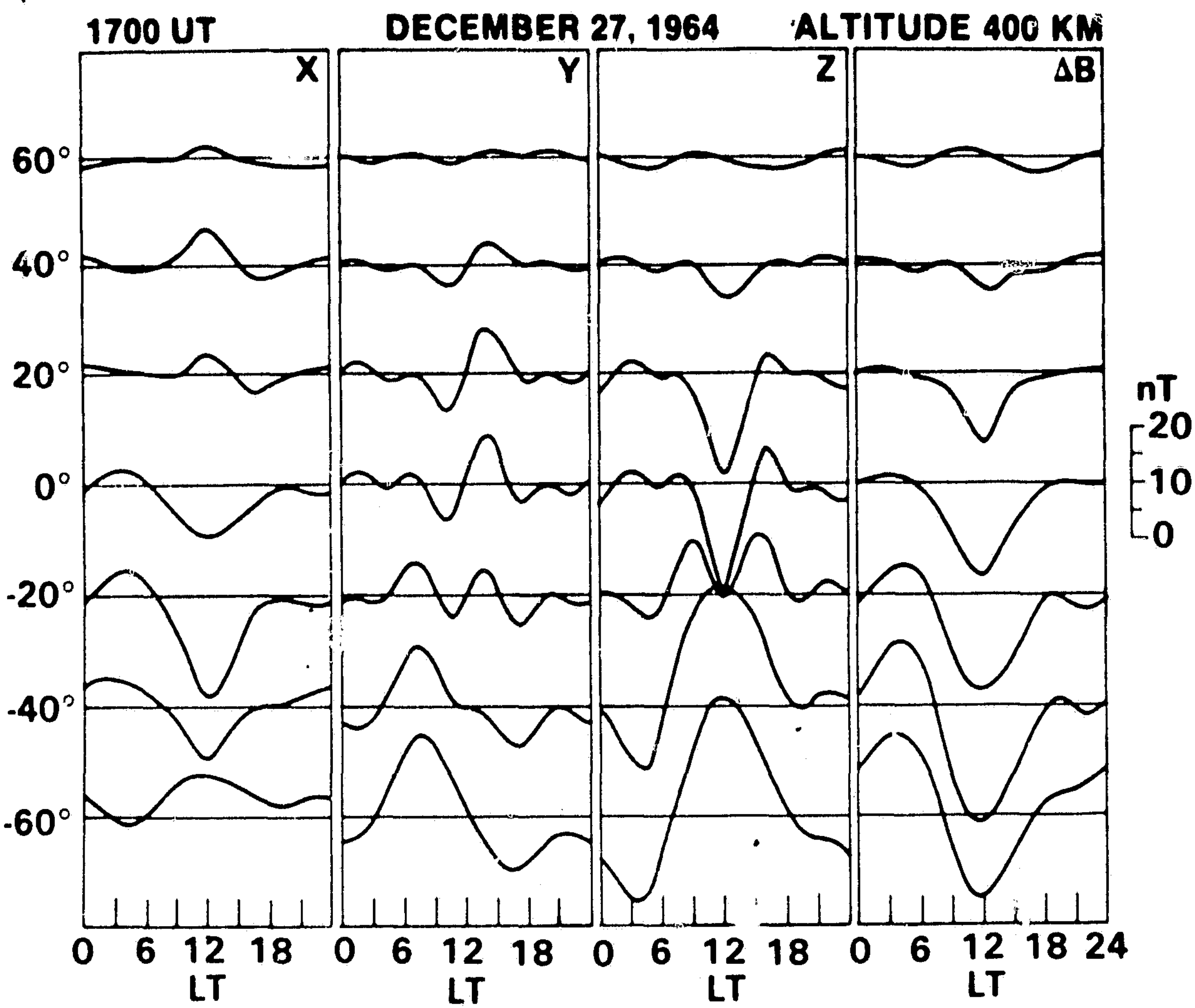
Satellite	Inclination	Altitude Range, km	Dates	Instrument	Approximate Accuracy, γ	Coverage
Sputnik 3	65°	440-600	5/58-6/58	fluxgates	100	USSR
Vanguard 3	33°	510-3750	9/59-12/59	proton	10	near ground station*
1963-38C	polar	1100	9/63-1/74	fluxgate (1 axis)	30-35	near ground station*
Cosmos 26	49°	270-403	3/64	proton	unknown	whole orbit
Cosmos 49	50°	261-488	10/64-11/64	proton	22	whole orbit
1964-83C	90°	1040-1089	12/64-6/65	rubidium	22	near ground station*
Ogo-2	87°	413-1510	10/65-9/67	rubidium	6	whole orbit
Ogo-4	86°	412-908	7/67-1/69	rubidium	6	whole orbit
Ogo-6	82°	397-1098	6/69-7/71	rubidium	6	whole orbit
Cosmos 321	72°	270-403	1/70-3/70	cesium	unknown	whole orbit
Azur	103°	384-3145	11/69-6/70	fluxgate (2 axis)	unknown	near ground station*
Triad	polar	750-832	9/72 to present	fluxgate	unknown	near ground station*

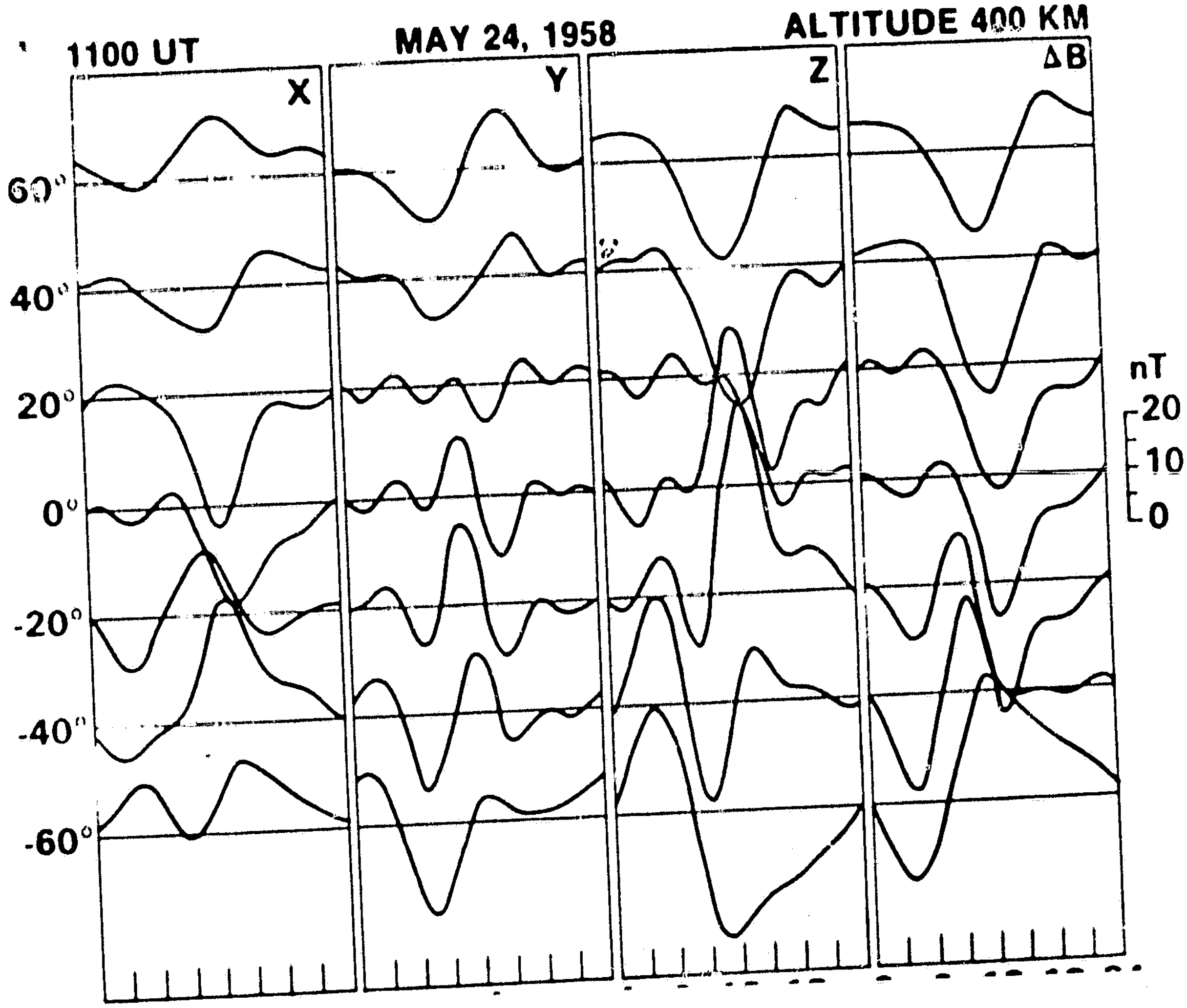
*'Near-ground station' indicates no on-board recorder. Data was acquired only when the spacecraft was in sight of a station equipped to receive telemetry.


UPWARD
CONTINUATION
500 KM
NP
70° N
50 N
220
240
260
SCALAR MAGNETIC
FIELD ANOMALIES
POGO SATELLITES
90°
80°
70°
60°
50°
220°
240
260°

ORIGINAL PAGE IS
OF POOR QUALITY

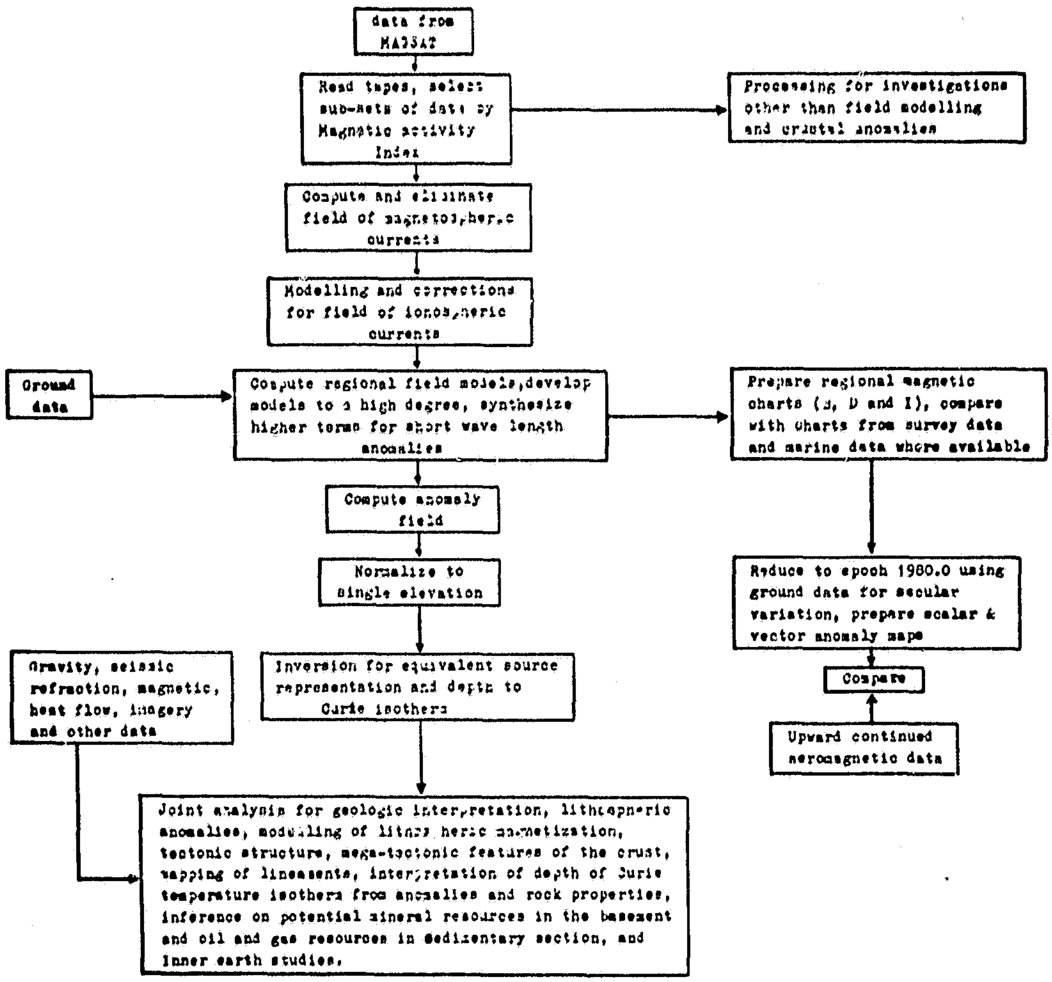



1700 UT
DECEMBER 27, 1964
ALTITUDE 400 KM
X
Y
Z
ΔB
60°
40°
20°
0°
-20°
-40°
-60°
nT
20
10
0
0 6 12 18
0 6 12 18
0 6 12 18
0 6 12 18 24
LT
LT
LT
LT



1100 UT
MAY 24, 1958
ALTITUDE 400 KM
X
Y
Z
ΔB
60°
40°
20°
0°
-20°
-40°
-60°
nT
20
10
0

BLOCK DIAGRAM



Mapping The Earth's Magnetic Field

B.P.Singh

Space-borne magnetic surveys may help find new mineral resources and unravel the Earth's mysterious past

IN THE year 2634 BC, a great battle was fought in the plains of Tcho-luo between the Chinese emperor Hoang-Ti and a minor prince, Tchi-Yeau. The prince produced a dense fog—the ancient equivalent to the modern smokescreen to confuse his enemy. The emperor was smarter. He put a small statue of a man, with one of its arms always pointing towards the south, on a chariot. With its help, the emperor's army was able to pursue the retreating enemy. The prince was captured and put to death.

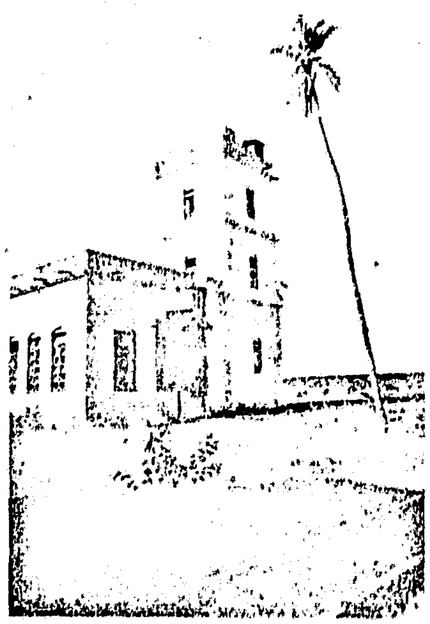
The ancients knew the use of magnetic compass for navigation. They thought that the compass-needle always pointed towards the Pole-star in the North. The modern scientists have gone a step ahead. They are using space technology to obtain the most accurate and up-to-date quantitative description of the Earth's magnetic field to locate potential mineral and oil resources and to mark out earthquake-prone areas.

The earth's magnetic field is unsteady and complex

In 1600, William Gilbert, a physician to Queen Elizabeth of England proclaimed that the globe of the Earth itself is a great magnet. Studies revealed that the Earth's magnetic field contained contributions from three sources. The main field could be described as similar to that produced by a huge bar magnet, with its centre near the centre of the Earth and with its axis tilted at an angle of about 11° to the axis of the Earth's rotation. The field strength is about twice as strong near the poles (50,000 nT, nT=neno Tesla, 1 nT = 10^{-5} gauss) as it is near the equator (30,000 nT). This magnetic field is not exactly a dipole field but consists of minute non-dipole components.

Though the Earth's magnetic field is largely dipolar in nature, the two poles north and south are not fixed; rather, they keep shifting. If their positions are averaged over a long span of time, say, a few ten thousands of years, they would coincide with the Earth's north and south poles. The dipole moment of the equivalent substitute magnet also keeps on changing slowly with a maximum rate of about one per cent per year. These changes introduce variation in the direction and strength of the magnetic field at the Earth's surface. This variation is called secular variation.

Fig. 1



The ground-based measurements of the magnetic field of the Earth taken by observatories such as the one at Alibag near Bombay, shown in Fig. 1 here, have been supplemented by measurements taken above the Earth's surface. Fig. 2 shows a magnetometer suspended from an aircraft. Air-borne field measurements, made generally at altitudes of 1 to 5 km, not only make the coverage of inaccessible areas feasible but are also more rapid and cheaper. But to map fields due to sources situated deep inside the Earth's crust whose effects cover larger surface areas, satellites orbiting the Earth about 200 km or higher are ideal. Fig. 3 shows a sketch of Magsat. The satellite's orbit was such that it gave full Earth coverage. Two star cameras helped very accurate determination of the attitude of the satellite. The magnetometers were kept 6 m away with the help of an extended boom to protect them from the magnetic disturbance caused by the star cameras

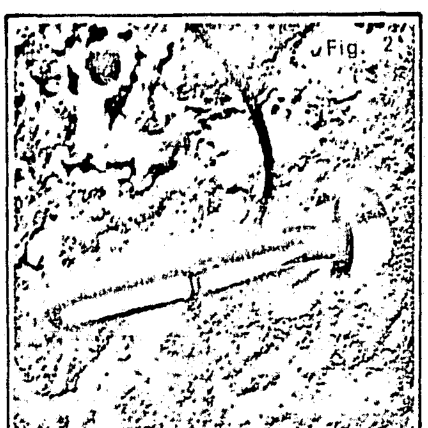


Fig. 2

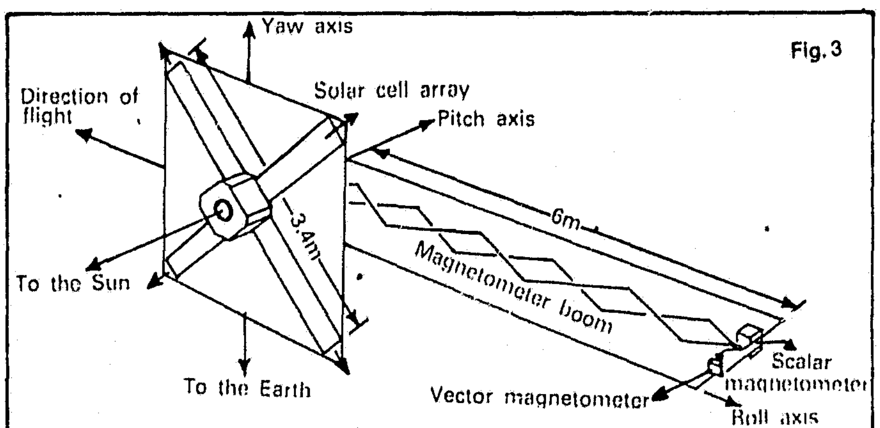
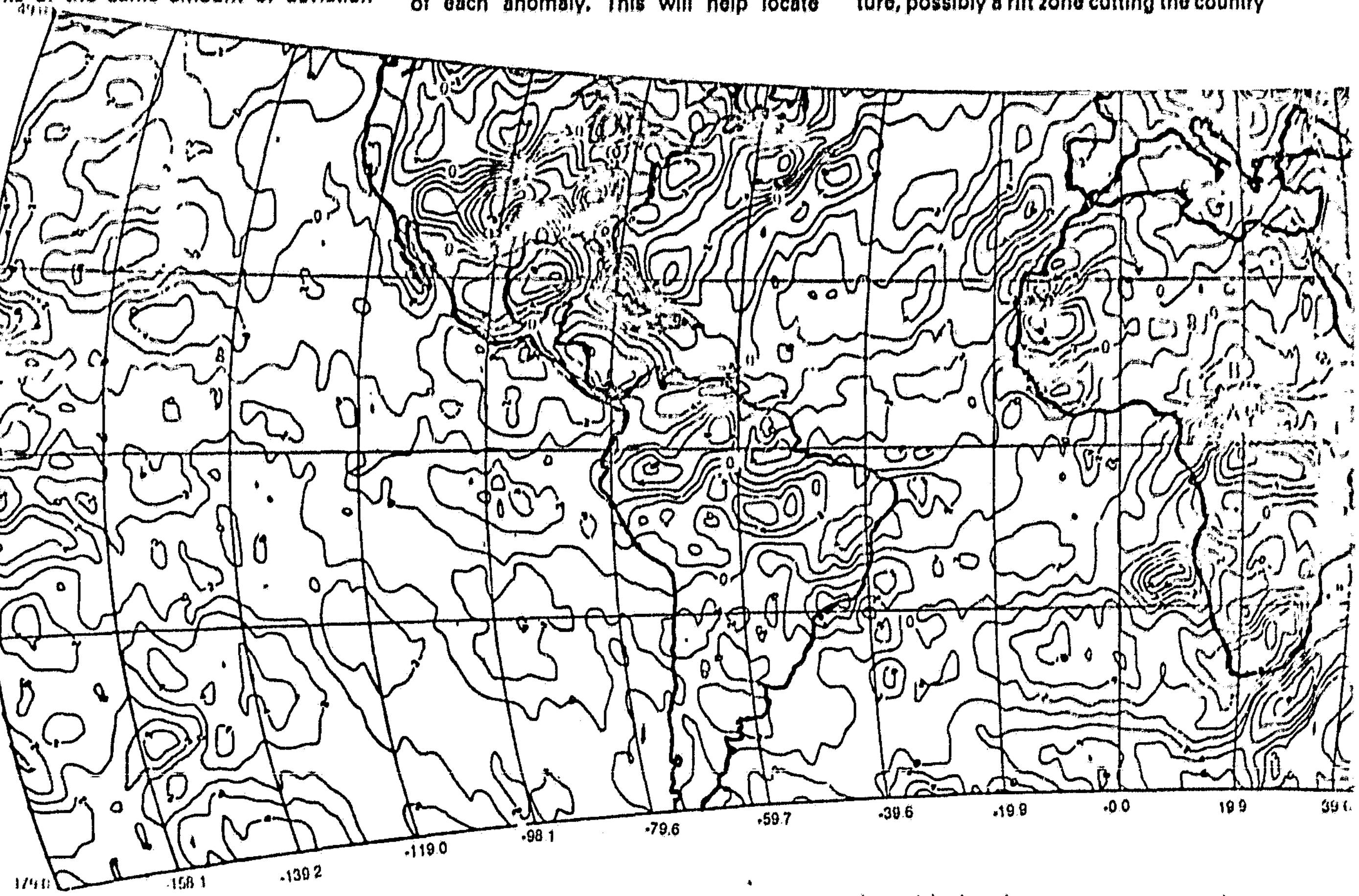


Fig. 3

Fig 4. The crustal magnetic anomaly map between the latitudes +49° and −49° prepared with Magsat data for a height of 347 km. The map was prepared by subtracting a model of the main field of the Earth, called the core field, from the measured field. The contours called isogams connect points of the same amount of deviation from the main field. The contours bearing positive numbers are coloured grey, whereas contours bearing negative numbers are coloured blue. The numbers are in units of nano Teslas. The aim of the map is to determine, along with other geophysical and geological data, the source and cause of each anomaly. This will help locate mineral and oil deposits and to identify features that could lead to a better understanding of the forces that shape the Earth. For instance, the important features of the Indian region seen in the map are the Himalayas and the Narmada-Son lineament. The latter is a newly identified structure, possibly a rift zone cutting the country



The higher multipole moments also vary with time and the observed secular variation is the sum of changes in all components.

Superimposed on the Earth's main magnetic field are "magnetic anomalies"—weak fields produced by materials within the Earth's crust. It is known that ferromagnetic materials, such as iron, lose their magnetisation above a certain temperature known as the Curie temperature of that material. With increasing depth, the Earth's temperature increases and the Curie temperature is reached at a depth of about 50 km. So the cause of magnetic anomalies is materials at shallower depths. The magnetisation could be acquired through two ways—induced and remanent. The first is magnetisation produced by the inductive influence of the Earth's magnetic field, similar to the magnetisation of an iron needle rubbed by a magnet; the second is residual, from the past history of formation of the rock. The anomaly map prepared from the Polar Orbiting Geophysical Observatory (POGO) satellite data being scalar (only strength magnitude) in nature could not resolve between the two components. However, the Magnetic Field Satellite (Magsat) data which is vector (both strength magnitude and direction) should be able to separate remanent and induced magnetisations.

The third contributor to the Earth's magnetic field is the external current system. An envelope of charged particles (both positive and negative) surrounds the Earth. The lower end of this envelope, called the magnetosphere, is the ionosphere. Due to the interaction of electromagnetic radiation and charged particles emitted from the Sun and the relative motion of the Earth, Sun and the Moon, a complex currrent system is generated in the magnetosphere and the ionosphere. The strength and location of these currents vary a great deal between magnetic quiet and disturbed periods which in turn depend upon the sunspot number.

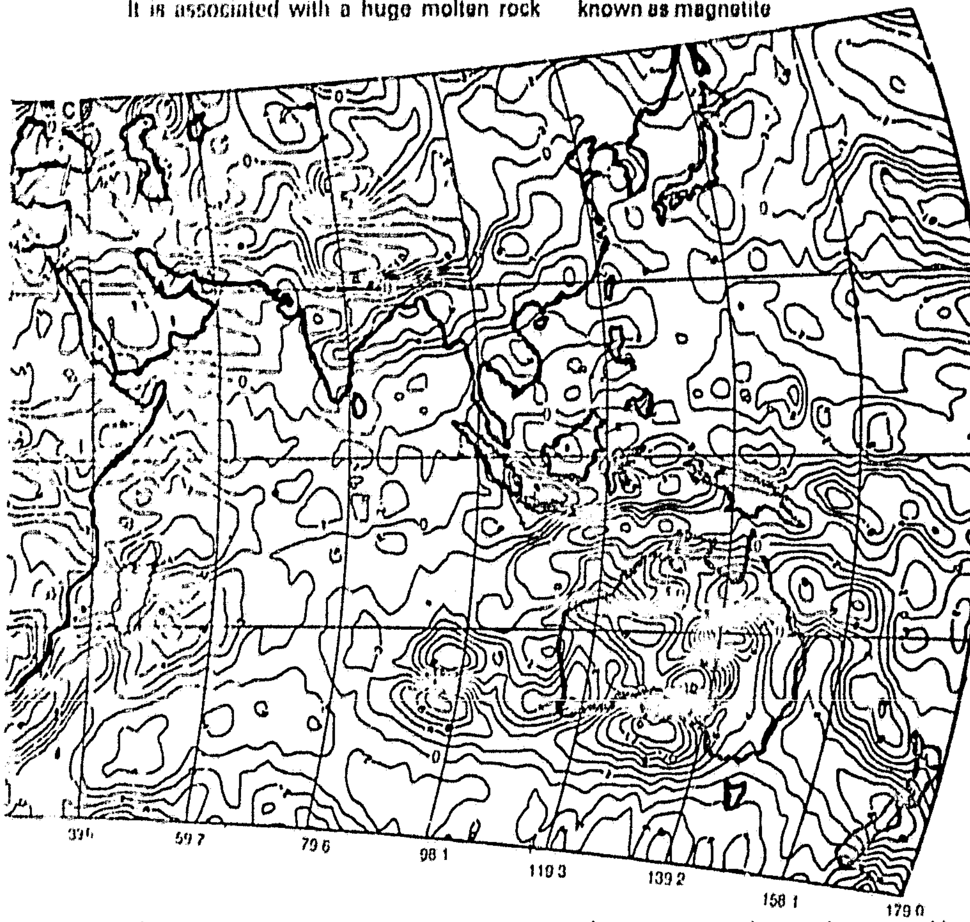
Resource survey

The location of a geological structure in resource survey is very much like locating the criminal in a detective story. The overall exploration problem is to gather clues from various kinds of measurements and to study them together to find the structure common to all. The common geophysical exploration techniques are magnetic, gravity and seismic. They help in estimating different physical properties of subsurface materials. The first is dependent on permeability, defined as the ratio of the intensity of magnetisation and the applied magnetic field, the second on density and the third on elastic properties. Such diverse measurements give information on the geologic structure of interest. The point of interest, however, is that the three surveys do not cost the same and this factor largely guides the order in which they should be undertaken. The cost ratios of magnetic, gravity and seismic survey are 1:10:100. No doubt, results from seismic surveys are most definitive, but its huge cost prohibits its use in reconnaissance work. Normally an explored region is first surveyed through magnetic field measurements.

Around the world, a number of land-based observatories situated at selected sites—for example, the

from Broach in Gujarat to Shillong in Meghalaya. It appears as a line of transition from a positive anomaly on the southern side to a negative anomaly on the northern side over the Himalayas. A very prominent low magnetic anomaly region called *Bangui anomaly* (marked A) is in central Africa It is associated with a huge molten rock The magnetic high (marked B) north of Bangui anomaly seem to follow a huge rift which nearly split apart Africa over 180 million years ago.

The top of the map shows a magnetic high (marked C) in the USSR. This area has a large quantity of strongly magnetic iron mineral known as magnetite



observatory at Alibag near Bombay (Fig. 1)—continuously measure the Earth's magnetic field. Since the early 17th century, seafarers have been preparing charts of the strength and direction of the magnetic field for better navigation. With the advent of self-orienting and direction-insensitive electronic magnetometers, magnetic surveys of inaccessible regions could be carried out from airplanes (Fig. 2). Airplane (aeromagnetic surveys) surveys are faster than ground surveys. Aeromagnetic surveys are particularly important for off-shore regions. Potential areas identified from magnetic methods are then studied in detail through gravity and seismic methods. Thus, the cost is considerably reduced and the exploration work also speeds up.

Satellite surveys

The geo-magnetic survey with satellites began in 1958 with the launch of Sputnik 3. It is important to distinguish between the signature of the crustal features (signal) in magnetic data collected from ground, air-borne and satellite-borne surveys. The signal has three components—short wavelength, medium wavelength and long wavelength. The short wavelength is generated by magnetic materials on the very top surface of the crust, the medium wavelength from materials at shallow depths and the long wavelength component from deep-seated structures. The ground data contain contributions from all sources, the air-borne data contain only medium and long wavelength components and the satellite data contain only the long wavelength component. In the context of exploration of resources at exploitable depths, the ground data offer the largest information content, and then air-borne data; for an exact calculation of the structure, the long and medium wavelength components from ground and long wavelength from aeromagnetic data must be subtracted. In that sense, results from satellite observations when available for the explored area, make the results from ground or air-borne surveys more accurate and meaningful.

A number of satellites measured the near-Earth magnetic field but with the launch of Magsat by NASA a new era was ushered in. Magsat was launched on 30 October, 1979 and was back on Earth on 11 June, 1980. Though the US Geological Survey and NASA were the principal users of the Magsat data, other investigators from the USA, and eight countries, including India, participated in the programme. The satellite altitude varied between 325 and 575 km. Besides measuring the strength of the field, it also measured its direction. This directional characteristic of the measurements made the data sent by Magsat very useful for crustal studies. Other special features of Magsat (Fig. 3) were: (i) a Sun-synchronous dawn-to-dusk orbit to reduce ionospheric components in the measured field; (ii) star cameras to accurately estimate the altitude; and (iii) good altitude determination.

How are the space-borne magnetic field measurements deployed to locate mineral deposits and to unravel the Earth's mysterious past? The first step in crustal studies using space-borne magnetic field measurements is to isolate the component of crustal origin from total field measurements as the field measured by instruments on a satellite is a sum of the main field arising from currents in the core of the Earth (or core field), the field arising from magnetised areas in the crust (called anomalous field) and the field arising from external currents in the ionosphere and magnetosphere. A major problem in this exercise arises from the fact that the measurements are being made from a fast-moving spacecraft in a continually changing orbit. Another problem is the very nature of the Earth's magnetic field which is in a state of perpetual disturbance arising from the complex interaction of solar-wind particles and the Earth's magnetosphere Also, it becomes difficult to separate spatial variations from the temporal disturbances in data collected with a moving vehicle.

Strengthwise, the main field is about 40,000 nT, the crustal component and the components from external currents are of magnitude ranging from tens of nT to a few hundreds of nT, depending upon time and spatial position. In Magsat data the ionospheric component is considered to be small as the satellite was placed in a Sun-synchronous dawn-to-dusk orbit. Only those days would be selected, which were geomagnetically quiet —undisturbed by solar activity— thereby producing very small variations due to external currents. After removal of core and external field contributions, the residual would give the anomalies.

The global map of the distribution of magnetic anomalies between the

ORIGINAL PAGE IS
OF POOR QUALITY

latitudes ±49° is shown on pages 40 and 41. The map can be used to study the magnetic properties of the largescale crustal regions of the Earth. Interesting features in the map can be picked up for more detailed studies. Through a joint analysis of anomalies in the magnetic field, gravity field, heat flow, etc and from the imagery of the crust, the geologically significant features of regions measured in hundreds or even thousands of km can be known. Once zones are identified and characterised on a global basis, they should provide useful information regarding the dominant forces and movements that shape the Earth. They will also help delineate segments of the crust into resource provinces which will lead to an assessment of the mineral resources of a region or of a country. So the most promising areas for future mineral exploration can be identified and it will be possible to determine even the exploration strategies.

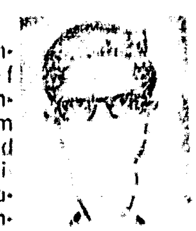
The map shows that a steep rise and fall is a unique feature of the Indian region. This could be due to the fact that the region is still tectonically active. We notice a magnetic low over the Indian Ocean—being zero below the tip of the peninsula—attaining a maximum value over the peninsular region, again becoming zero near the Narmada-Son lineament. The Narmada-Son lineament runs from 21°N, 71°E in the west coast of India to Rajmahal Hills. Observations indicate that it could be associated with a rift-like structure buried deep under a thick layer of sediments. The continuing cyclic variation becomes a low over the Himalayas. These patterns are also present to a significant extent in gravity anomalies and *subcrustal stresses* computed for the Indian region. The fact that these patterns are seen at satellite heights indicates their deep-seated origin and a modelling of these data may provide some unique information on the structure of the Earth's interior below India and on geodynamic processes. It is well-established now that tectonic processes that contribute to the dynamics of the Earth's crust (that is, plate motion, earthquakes, volcanism, and mineral formations) are related to the processes that originate in the mantle and core.

Scientists from the Indian Institute of Geomagnetism are preparing a regional geomagnetic reference field and magnetic anomaly maps over India and its neighbouring areas with the help of Magsat data. They are also studying in detail the transient variations in the magnetic field. By comparing magnetic data with gravity data from Geos-3, Robert F. Brammer of the USA is investigating Eastern Indian Ocean area. Igor I. Gil Pacca from Brazil is using Magsat data to study the structure, composition and thermal state of the crust in Brazil. Recently huge diamond deposits have been found in the Amazon basin which unlike the diamond deposits in Africa are not associated with a mineral called kimberlite. In Africa kimberlite is found exclusively in regions of low magnetic anomalies. It will be interesting to investigate the various combinations of geological causes which are responsible for the formation of diamond deposits. Paolo Gasparini of Italy is calculating, for the Mediterranean area, the depth of Curie temperature which indicates the depth of magnetic crust beyond which, because of high temperature, all material is nonmagnetic. He will relate it to areas of volcanic activity. Some of the magnetic anomalies may be associated with regions having a thin magnetic crust from which heat flows out of the Earth's interior.

An important mission objective of Magsat is to compute an accurate description of the Earth's main (core) field. This objective is as important as the crustal studies—basically because the accuracy of one depends upon the accuracy of the other. Development of a good model for the main field will contribute to: (i) a more accurate magnetic field, which is often needed, in ground, sea or air-based magnetic surveys in geophysical prospecting, (ii) an accurate separation of the main field to isolate components originating from ionospheric or magnetospheric current systems, and (iii) the study of the Earth's core and core-mantle boundary. While previous POGO data were unable to give a good representation of the model field as the measurements were only scalar in nature, the Magsat, with vector measurements, will provide adequate data to develop a good model.

The magnetic data have other uses also. For instance, they can help study the question, is the Earth heading towards another magnetic field reversal? The preliminary phase of the analysis of Magsat data by R. A. Langal and his co-workers at the Goddard Space Flight Center (USA) showed the continuing decrease of the strength of the Earth's dipole magnetic field at a rate of 25 nT per year. If this rate of decrease continues, the Earth's field would reverse in about 1,200 years. We do not know enough either by laboratory or theoretical experiments to forecast the change of the Earth's magnetic field. Core dynamics is complex, because it is unseen and speculative, because we can only imagine what happens there and perhaps it "attracts" us because we do not know it at all.

Fig 5 One of the sources of low magnetic anomaly could be a region experiencing intense plate tectonic activity. An example is the Himalayas as shown in this photo taken by Apollo 7 spacecraft. This mountain range is supposed to have formed due to the slamming of two huge crustal slabs of the Earth



Prof. Singh is with the Indian Institute of Geomagnetism, Bombay. He did MSc from Bihar University and PhD from Queen's University, Kingston, Canada. His main research interest is the use of variations in geomagnetic field in studies of the Earth's interior.